A Practical Way to Generate Protons (Deuterons) of Energy Between 500 and 1000 eV.

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Abstract. *Research tools used in the field of d/d fusion are protons (deuterons) accelerators producing ion beams of energies between 10 keV up to several MeV . Another source of protons (deuterons) are low pressure electrical discharge, yielding ions of energies between 1 to some tens of eV. Based on this second source, a way to generate protons (deuterons) in the range 500 to 1000 eV is described.*

1. Introduction

It was recently proposed [1] to study d/d fusion reactions initiated by bombarding targets loaded with deuterium, with deuterons of energies between 500 and 1000 eV. These levels of energy can easily be achieved by using ion generators of several kW power, that are now available on the market (surface treatment, electronic industry). They can produce ion (proton, deuteron) beams of high intensity (several A) with ion energies in the range 100 to 4000 eV and are thus able to work in the 500 to 1000 eV energy window. Due to budget limitations, such an equipment cannot be envisaged for the time being. The existing laboratory accelerators are limited on the low energy side to some 5 to 10 keV. A device was thus developed, based on the acceleration of ions generated in a low pressure (50 Pa) glow discharge. Ionic current up to 30 µA, with ion energies of some 850 eV are expected.

2. Principle of the device

Glow discharges in hydrogen isotopes at pressures between 10 to 50 Pa, mainly yield H^+ (D^+) ions and atomic hydrogen (deuterium). The principle of the device is described in *Fig 1*. Technical features to control operating conditions (pressures cascades for instance) are given in *Fig 2*.

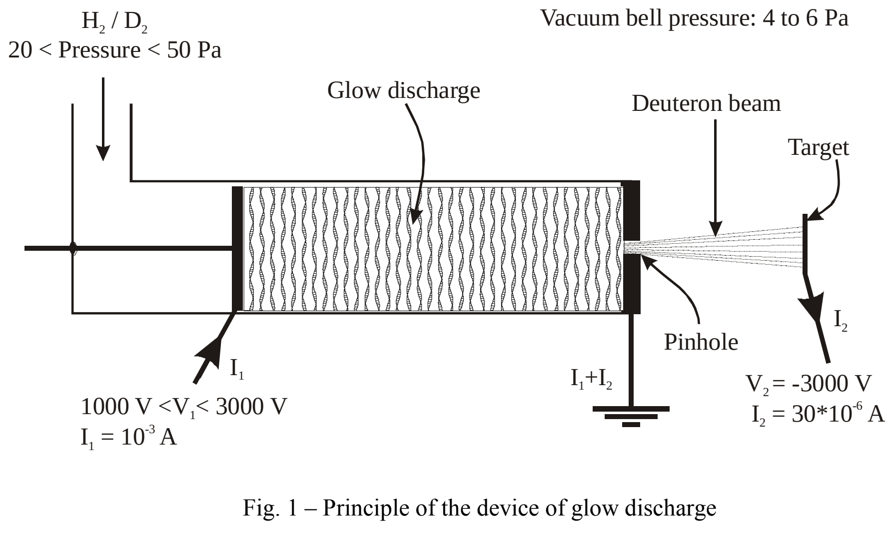

Fig. 1 – Principle of the device of glow discharge

The concentration of molecular deuterium entering the system is some $8*10^{21}$ m^{-3} (at a representative pressure of 30 Pa) and the current I_1 of the main glow discharge is measured to be 10^{-3} A for a voltage V_1 = + 2000V. Part of the deuterons, generated in the glow discharge, go through a pinhole (0.5 mm diameter) in the earthed electrode and are collected on the target. At low voltage of the target, the current I_2 is some $5*10^{-6}$ A, increasing from 30 to $40*10^{-6}$ A when V_2 reaches 3000V. At a pressure of 5 Pa, the mean free path of hydrogen (deuterium) is round 2 mm. For V_2 = 3000 V and a distance between the grounded electrode and the target of 5 mm, the mean energy of the D^+ ions impinging the target can be estimated to be some 850 eV (See below more details on the modeling of the discharge)

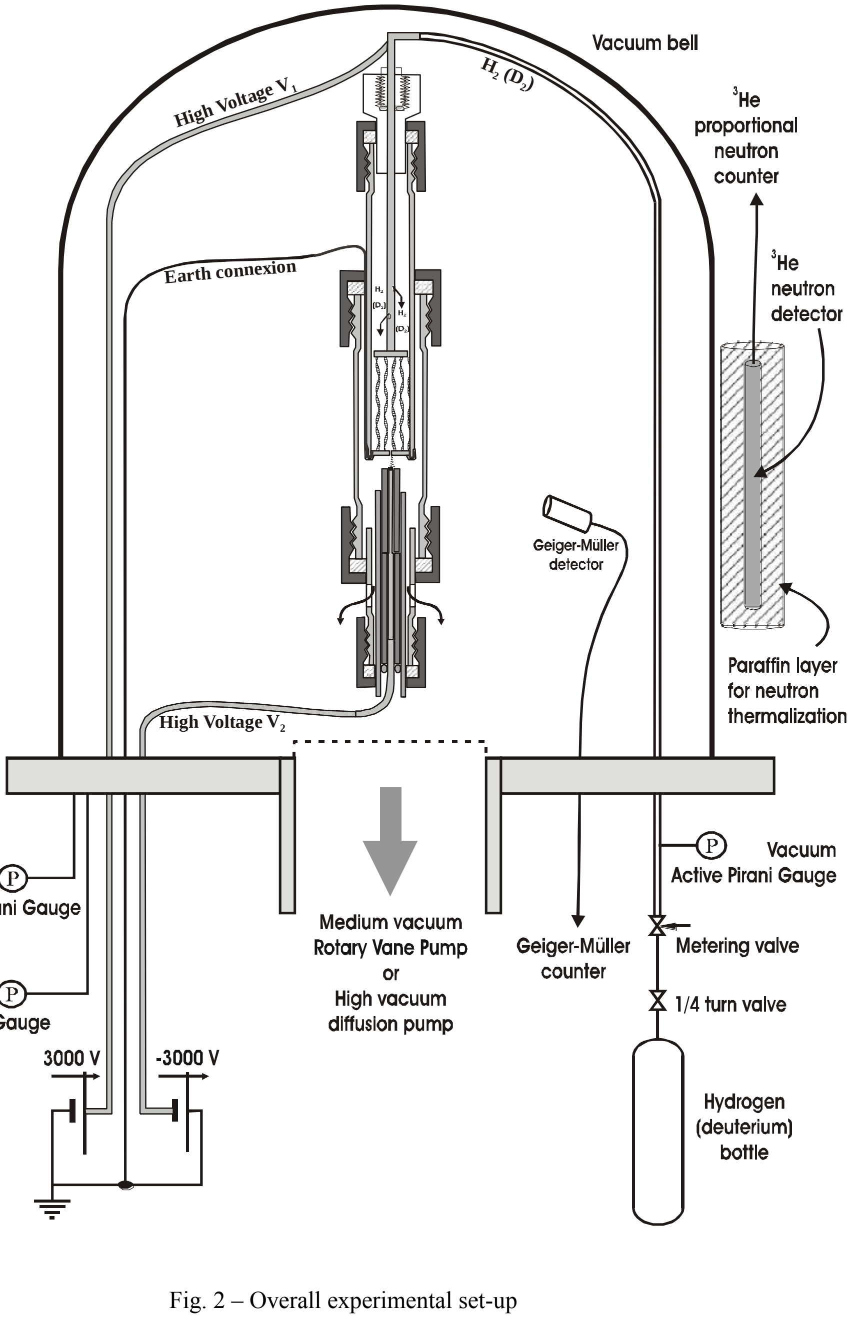

Fig. 2 – Overall experimental set-up

3. Detailed description of the device

3.1 Over all experimental set-up:

The overall experimental set-up is given *Fig 2*.

The reactor is placed in a vacuum bell. Pressures down to 1 Pa can be reached when using the medium rotary pump and down to 10^{-2} Pa when using the combination rotary/diffusion pumps. The pressures before and after the reactor are measured by 2 Pirani gauges, when the rotary pump only is used (1 Pirani before and 1 Penning gauge after the reactor when the combination rotary/diffusion pumps is used). Hydrogen (deuterium) gas is fed into the reactor through a metering valve. The pressure drop through the pinhole of the glow discharge cathode is measured by the pressure gauges. The glow discharge cathode (tantalum) is connected to earth. The glow discharge anode (stainless steel) is connected to a positive high voltage generator (GAMMA High Voltage Research) delivering a regulated current up to 3 mA under a regulated voltage up to 20 kV. The target is connected to a negative high voltage generator (HP 6110 A) delivering a regulated current up to 6 mA under a regulated voltage up to 3 kV. Pressures, currents and voltages are monitored, using an AOIP LS20 monitoring device.

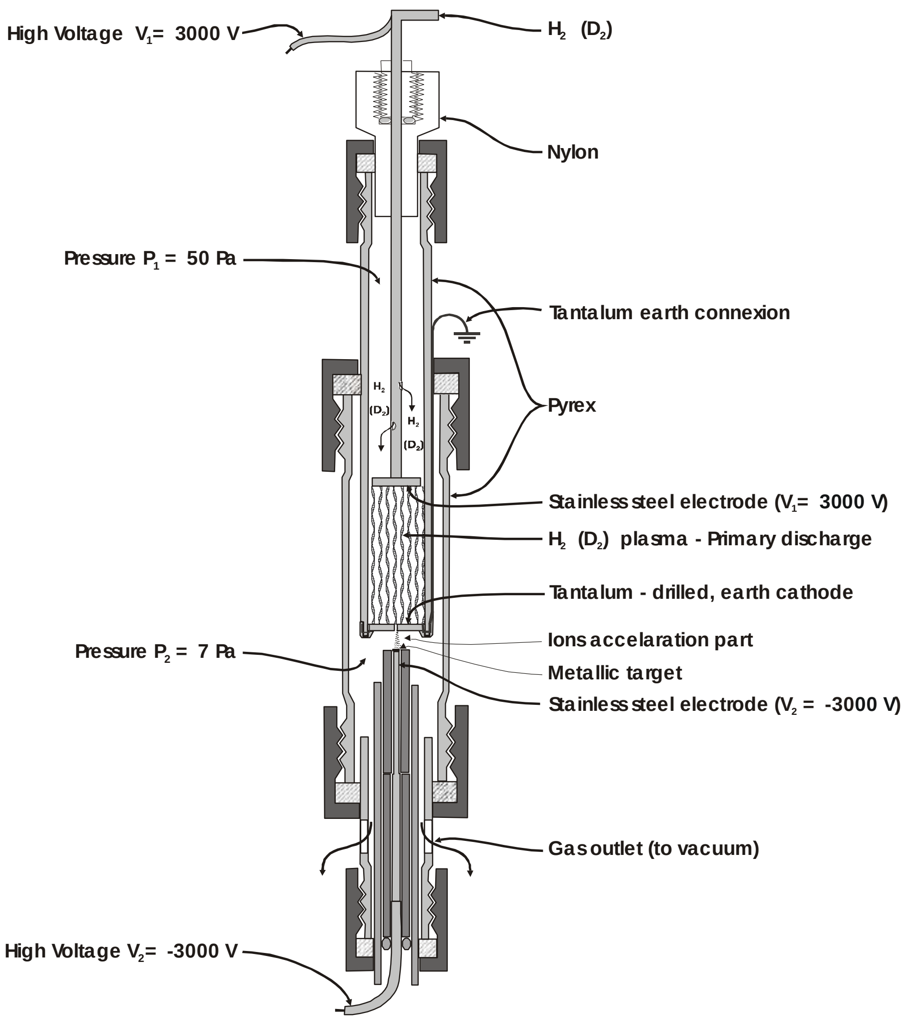

Fig. 3 – Reactor design

3.2 Reactor design

The reactor is shown on *Fig 3*.

The glow discharge is struck between the stainless steel anode and the tantalum cathode. A pinhole (surface $S_{Pin\ Hole}$) in the cathode (surface $S_{Cathode}$) allows the hydrogen (deuterium) flowing through the glow discharge at a pressure P_1 of a few tens of Pa, to expand down to a pressure P_2 of a few Pa. A current of protons (deuterons) also flows with the expanded hydrogen (deuterium), through the pinhole and is accelerated, under vacuum, by the high negative voltage of the target. Energies of the ions up to some 850 eV are expected (see below modeling of the discharge).

An helium 3 neutron detector with 2 cm paraffin thermalization covering is placed outside the vacuum bell (see above)

4. Modeling of the process

4.1 The glow discharge

The principles for a global model of a glow discharge can be found in [2]. The particles balance yields the temperature of the electrons T_e and the power balance yields the ions (and electrons) concentrations $n_0 = n_i = n_e$. If l is the length, R the radius of the plasma of the cylindrical discharge (*Fig 4*) and n_g the neutral gas concentration, the particles balance expresses that the charged particles production through ionization (coefficient K_{IZ} $m^3 s^{-1}$) is equal to the charged particles lost by recombination in the gas (axial losses, dimensionnless fraction h_l) and on the surface of the reactor (surface losses, dimensionless fraction

$K_{IZ} n_g n_0 \pi R^2 l = \left(2\pi R^2 h_l n_0 + 2\pi R l h_R n_0\right) u_B$, with $u_B = \sqrt{\dfrac{kT_e}{m_i}}$ (Bohm velocity of the ions, mass m_i)

From this balance, the following relation is obtained:

$$\frac{K_{IZ}(T_e)}{u_B(T_e)} = \frac{1}{n_g d_{eff}} \qquad (1)$$

with $d_{eff} = \dfrac{1}{2} \dfrac{Rl}{Rh_l + lh_R}$, (m) linear dimension describing the geometry of the plasma.

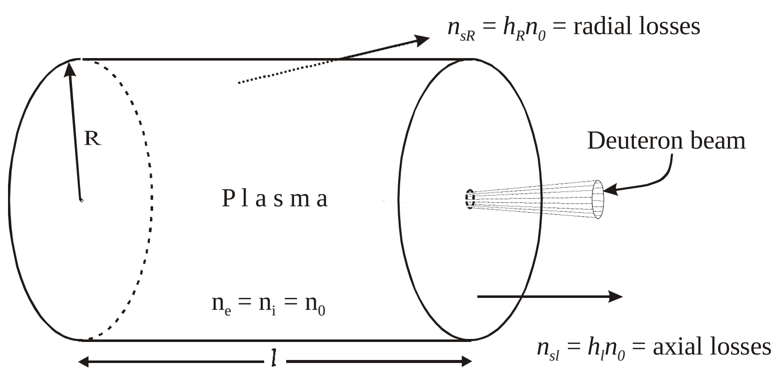

Fig. 4 – The glow discharge

The energy balance can be written $P_{abs} = \left(h_l n_0 2\pi R^2 + h_R n_0 2\pi R l\right) u_B E_T$ expressing that the total power absorbed P_{abs} is used for electron-ion pair production, E_T being the total energy required per pair (ionization, excitation, ion acceleration…)
From this balance, the following relation is obtained:

$$n_0 = \frac{P_{abs}}{A_{eff} u_B E_T} \qquad (2)$$

with $A_{eff} = 2\pi R(Rh_l + lh_R)$, (m^2) surface dimension describing the geometry of the plasma.
Relations (1) and (2) combined with the relation:

$$A_{eff} d_{eff} = \pi R^2 l \text{ , } \left(m^3\right) \text{ (plasma volume)} \qquad (3)$$

allow the calculation of the parameters of the discharge $\left(n_0 \text{ and } T_e\right)$, using the experimental relation between T_e and $n_g d_{eff}$ given by *Fig 5* which is valid for any discharge. T_e is used as the fitting parameter.
Typical values for the conditions used (P_1 = 50 Pa, V_1 = 3000 V, I_1 = 3 mA) are $n_0 = 2*10^{16}$ m^{-3}, temperature of the electrons T_e = 4,2 eV and energy of the ions leaving the cathode 2 eV.

4.2 The positive ions acceleration zone

A fraction of the positive ions (protons, deuterons) generated in the discharge (in the ratio $S_{Pin\ Hole}/S_{Cathode}$) are expanded, with the neutral atoms, from P_1 to P_2, through the pinhole of the cathode, which they leave with an energy of a few eV (see above). They are accelerated by the target negative voltage. Their mean free path λ is assumed to be the same as atomic hydrogen, $\lambda_H \ (mm) = \frac{100}{P_2 \ (Pa)} 10^{-1}$. For a distance cathode-target of 5 mm and a target voltage of -3000 V, the energy of the protons (deuterons) impinging on the target will be some 850 eV for P_2 = 7 Pa, assuming that the expansion is complete at a few (2 to 3) mm from the cathode.

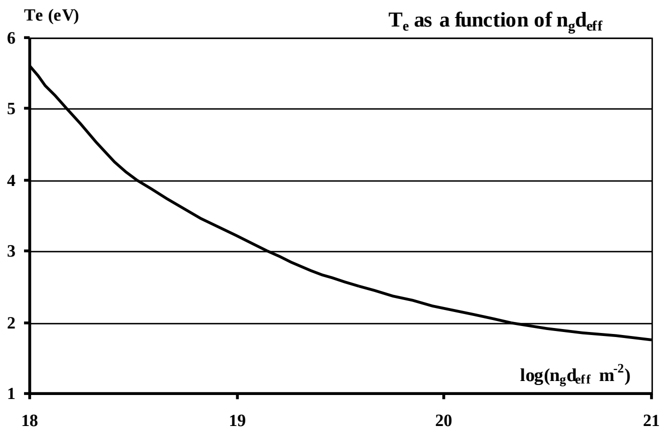

Fig. 5 – T_e as a function of $n_g d_{eff}$

5. Monitoring the fusion reaction

To monitor the fusion reaction, the production of neutrons will be measured, using a 65NH45 Helium 3 detector (active detection surface S = 100 cm^2). The active part of the detector is surrounded by a cylindrical layer of paraffin, resulting in a paraffin thickness of 2 cm. The spectra are recorded using a CANBERRA 2006 pre-amplifier, an ORTEC 570 amplifier and a CANBERRA AccuSpec NaI multi-channel analyser. The back ground of the laboratory has been measured and found to be equal to 1.5±0.2 10^{-2} cps, corresponding to a background neutron flux $\Phi_{N-back.}$ of some 1.5 10^{-4} cps/cm^2.

Assuming an efficiency of 100% of the detection chain, the neutron activity $A_{N-meas.}$ of the target, will be evaluated from the measured neutron flux $\Phi_{N-meas.}$ by $A_{N-meas.} = 4\pi R^2\left(\Phi_{N-meas.} - \Phi_{N-back.}\right)$, (Bq) , with R being the distance target/detector (taken as 25 cm which is the minimum distance between the cylindrical detector and the target). Thus calculated, $\Phi_{N-meas.}$ gives a low side value of the neutron activity of the target, that will then be compared to the value $A_{N-\text{mod.}}$, computed from the model described in [1].

In order to detect possible γ emission from the target, a Geiger counter has been placed inside the vacuum bell.

6. Conclusion

The proposed device will be used to test various targets (diameter 2 to 4 mm). The choice of these targets (nature of the metal and its physical and chemical characteristics) will be guided by the results already obtained in the field. In a first step, the objective will be to verify the validity of phenomenological model. In a second step, the possibility of gaining a better knowledge of the mechanisms involved could result in a further improvement of the targets.

Finally, in case of success, ion generators, with kW power level and energies of the ions in the range 200 to 4000 eV, that are now available on the market (surface treatment and electronic industries) could be used for an industrial up-scaling.

7. References

[1] J. Dufour. "Evaluation of d/d reaction rates in metallic lattices as a function of the deuteron energy. A phenomenological model of nuclear fusion in solids" *ICCF15 Proceedings. Rome 5-9 October 2009*

[2] Lieberman and Lichtenberg "Principles of Plasma Discharges and Materials processing" *John Wiley and Sons*